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ROCK MASS CLASSIFICATION AND THEIR USES IN MINING

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ABSTRACT
The rock mass type in which all perform mining activities is of particular importance when choosing appropriate techniques and technologies to open the mine and exploitation of mineral resources.
This paper presents the rock mass classification that is mostly used in mining. Also an example of rock mass classification according to Bienawski is provided.

1. Introduction

There are several rock mass classifications that relate to their quality and condition. This paper will present only those mostly used in mining.

These classifications are made based on systematization of acquired experience and numerous research studies in mining and tunnel construction.

2. The mostly used rock mass classifications

There are many rock mass classifications, which we will mention: M.M.Protogjakonov`s classification (1926) Terzaghi`s classification (1946), Brauns-Stiny`s classification, Laufer`s classification (1958), Wickham`s, Tiedemann`s and Skinner`s classification (1972).

However the most significant contemporary classifications, which are still in use: Deer`s classification (1967), Barton`s classification (1974), Bieniawski`s classification (1973, 1974, 1976, 1979, 1989), Laubscher`s classification (1979) , Kendorski`s classification (1983).

2.1. Classification by M.M.Protodjakonov - 1926

This classification has often been used in mining. The Protodjakonov`s rock mass classification i divided rock mass into 15 categories based on coefficient of strength. Protodjakonov understood this coefficient as a general indicator of rock mass resistance on the outside influences and it is derived from uniaxial compressive strength.

$$f = \frac{\sigma_c}{10} \qquad (1)$$

f – coefficient of strength;
σ_c– uniaxial compressive strength [MPa].
The following table given the Protodjakonov`s rock mass classification.

Because this classification uses only one indicator to describe the rock mass condition, recently it has been used less frequently.

Table 2.1. Classification of the rock material by Protogakonov

Category of material		Rock type or ore	Coefficient of strenght - f	Virtual angle of internal friction (°)[φ]
I	Very strength	Very strength big and tough quartzite and basalt. Other very strength materials.	20	87°08'
II	Very strength	Very strength granular rocks, quartz porphyrite, very strength granite, schist quartzite, less strength quartzite, very strength sandstone and limestone	15	86°11'
III	Strength	Granite (fine-grained) and other eruptive rock. Very strength limestone and sandstone .Quartz ore veins. Strength quartzite. Strength ores of iron.	10	84°18'
III – a	Strength	Limestones (strength) Strength sandstones. Strength dolomite Pyrite.	8	82°50'
IV	Moderate strength	Cracked quartzite. Sandstone. Ores of iron (moderate strength).	6	80°32'
IV - a	Moderate strength	Sandstone clay schist. Schist sandstones	5	78°41'
V	Moderate strength	Strength clay schists. Weak sandstone and limestone.Soft conglomerate	4	75°85'
V – a	Moderate strength	Different schist –weaker. Marl, Cracked quartzite weaker iron ore	3	71°34'
VI	Soft	Soft schist, very soft limestone, chalk,halite, gypsum. Frozen ground.Antracite, marl, cracked sandstone, stickly gravel, rocky ground.	2,2	63°26'
VI – a	Soft	Sandstone ground Decomposed schist, gravel strength coal, hardened clay, wet soft ore of iron.	1,5	56°19'
VII	Very soft	Clay (compressed), coal with medium strength, solid gray, clay soil	1	45°00'
VII – a	Very soft	Easy sandstones clay, forest, soft coal.	0,8	38°40'
VIII	Soil	Agricultural soil, peat, forest, clay sand, dirty sand.	0,6	35°00'
IX	Mould	Sand, fine grained gravel, filled land, dug coal	0,5	30°58'
X	Liquid	Wet sand, muddy land ,wet forest.	0,3	16°42'

2.2. Classification by Deer

This classification is based on rock mass jointed, which is rated based on drill core longs.
RQD (Rock Quality Designation) is used as an indicator of the rock mass jointed and is calculated using the following formula:

$$RQD\ (\%) = \frac{L_p}{L_t} \cdot 100 \qquad (2)$$

RQD – Rock Quality Designation;
L_p– length of core pieces > 10 cm length;
L_t – total length of core run.

RQD is only linear indicator of the rock mass integrity and it depends of the drilling direction. This indicator is not only sufficient of rock material description, because isn't take into account: joint`s orientation,

width and the infilling material, roughness of the joint`s walls, stresses conditions and underground water conditions [4].
When no core is available but discontinuity traces are visible in surface exposures or exploitation adits, RQD may be estimated from the number of discontinuities per unit volume or the number per unit length.

$$RQD\ (\%) = 115 - 3{,}3J_v \qquad (3)$$

J_v – the sum of the number of joints per unit volume or the number per unit length (when $J_v < 4{,}5$, then RQD = 100 %).

The joints number per unit volume of rock mass can be determined as the sum of joints per unit length for each family of joints. For example:

family 1,	6 joints per 20 m
family 2,	2 joints per 10 m
family 3,	20 joints per 10 m
family 4,	20 joints per 5 m

$J_v = 6/20 + 2/10 + 20/10 + 20/5 = 0{,}3 + 0{,}2 + 2 + 4 = 6{,}5$ joints/m^3
RQD can be determined based on the mean distance measurement between joints and using the equation:

$$RQD\ (\%) = 100\ \cdot e^{-0{,}1\lambda}(0{,}1 \cdot \lambda + 1) \qquad (4)$$

λ - average number of joints per 1 m'

$$\lambda \cong 1/X$$

X – average value on distance between joints

$$X = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (5)$$

2.3. Classification of Norwegian geotechnical institute

Classification of Norwegian geotechnical institute is often used because of its comprehensiveness, as well as for complex description of rock mass. This classification is developed and proposed by Barton, Lien and Lunde (1974) [1].

Rating of rock mass by this classification is performed based on six parameters related to the following equation:

$$Q = \left(\frac{RQD}{J_n}\right) \cdot \left(\frac{J_r}{J_a}\right) \cdot \left(\frac{J_w}{SRF}\right) \qquad (6)$$

where:
RQD - Rock Quality Designation,
J_n – joint set number,
J_r – joint roughness number,
J_a – joint alteration number,
J_w – joint water reduction factor,
SRF – stress reduction factor.

Depending on the value of Q rock mass assessment is classified as:

very good rock	$Q > 100$
good rock	$10 < Q < 100$
fair rock	$1 < Q < 10$
poor rock	$0{,}1 < Q < 1$
very poor rock	$Q < 0{,}1$

2.4. Geomechanical classification for jointed rock mass (Bieniawski, 1973- 1989)

Geomechanical classification or Rock Mass Rating (RMR) system created by Bieniawski, 1973 year (see table 2.2).

Table 2.2. Bieniawski`s classification

A. Classification parameters and their ratings

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index I_s (MPa)	>10	4 - 10	2 - 4	1 - 2	For this low range only σ_c		
		Uniaxial comp. strength σ_c (MPa)	>250	100-250	50-100	25-50	5 - 25	1 - 5	<1
	Rating		15	12	7	4	2	1	0
2	RQD (%)		90-100	75-90	50-75	25-50	<25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities (m)		>2	0,6-2	0,2-0,6	0,06-0,2	<0,06		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See D)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m structure length (l/m)	Никаков	<10	10 - 25	25 - 125	>124		
		Joint water press /σ_1	0	< 0,1	0,1 - 0,2	0,2 - 0,5	> 0,5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Број на поени		15	10	7	4	0		

B. Rating adjustment for discontinuity orientations (See E)

Strike and dip orientations		Very favourable	Favou-rable	Fair	Unfavou-rable	Very Unfavourable
Ratings	Mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

V. Rock mass classes

Ratings	100←81	80←61	60←41	40←21	<21
Class number	I	II	III	IV	V
Description for rock	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

G. Meaning of rock classes

Class number	I	II	III	IV	V
Average stand-up time	20 yrs. for 15 m	1 ryrs. for 10 m	1 week for 5 m	10 h for 2,5 m	30 min for 1 m
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (˚)	>45	35 - 45	25 - 35	15 - 25	< 15

D. Guidelines for classification of discontinuity conditions

Discontinuity length	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Rating	6	4	2	1	0
Separation	None	< 0,1 mm	0,1 - 1 mm	1 - 5 mm	>5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Unweathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

E. Guidelines for classification of discontinuity conditions

Strike perpendicular to structure axis		Strike parallel to structure axis	
Drive with dip - Dip 45-90˚	Drive with dip - Dip 20-45˚	Dip 45-90˚	Dip 20-45˚
Very favourable	Very unfavourable	Very unfavourable	Fair
Drive against dip - Dip 45-90˚	Drive against dip - Dip 20-45˚	Dip 0-20 - Irrespective of strike	
Fair	Unfavourable	Fair	

The following six parameters are used do classify a rock mass using the RMR system:

- Uniaxial compressive strength of rock material
- Rock Quality Designation (RGD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation od discontinuities

3. Application of Bienawski`s classification in mining

Table 3.1 shown physical and mechanical characteristics of the schist from Sasa mine field, revir Svinja Reka, obtained by laboratory tests that are required for this survey as follows: bulk density γ [MN/m^3], uniaxial compressive strength σ_c [MPa], tensile strength σ_t [MPa], cohesion C [MPa], angle of internal friction φ [°], Poisson coefficient ν and modulus of elasticity E [MPa] [3].

Table 3.1. Physical and mechanical characteristics of the schist

DESCRIPTION	γ [MN/m^3]	σ_c [MPa]	σ_t [MPa]	C [MPa]	φ [°]	ν	E [MPa]
schist	0,0270	98	6,10	14,00	32,0	0,120	32000

Based on the laboratory test data and additional conducted in-situ research, such as investigative drilling, groundwater flow, distance between joints etc. the rock material classification is performed by Bieniawski `s classification (table 3.2).

Table 3.2. Data for the schist

According to table	Parameter	Value (condition)	Rating (RMR)
2.2: A.1	Uniaxial comp. strength - σ_c	98 MPa	7
2.2: A.2	RQD	30%	8
2.2: A.3	Spacing of discontinuities	400 mm	10
2.2: A.4 (D)	Condition of discontinuities	Slicken sided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	10
2.2: A.5	Underground water	Dripping, inflow 25-125 l/min	4
2.2: B	Discontinuity strike	Fair	-5
Total			34

According to Bieniawski`s classification (1989), the schist from Sasa mine field we classified in IV class and it is can describe as poor rock with cohesion C = 100 – 200 kPa and angle of internal friction ρ = 15 – 25 °.

4. Conclusion

Before begining of any mining activities should be carried out investigations that will determine the quality of the mineral resource and the quality of the associated rocks. Such data is necessary for the selection of appropriate techniques and technologies of mine opening and exploitation of mineral resources.

5. References

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